Research - Embedded Chat Widget Architecture for Decentralized AI Interfaces: WebSocket, PWA, and Bot Bridges

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Abstract

Decentralized AI interfaces require multi-channel communication architectures that span web browsers, mobile platforms, and messaging applications while maintaining sovereign control over data and inference. This paper presents a comprehensive architecture for embedded chat widgets that serve as the primary human-AI interaction surface in sovereign AI systems. The architecture integrates WebSocket-based real-time communication, Progressive Web Application (PWA) capabilities for mobile and offline access, and bot bridges for Telegram, Discord, and WhatsApp channels. We analyze the connection management layer, which handles reconnection with exponential backoff, message queuing for offline resilience, and session persistence across channels. The widget implements a plugin-based rendering engine supporting rich content types: Markdown, code blocks with syntax highlighting, Mermaid diagrams, LaTeX equations, interactive data tables, and streaming token-by-token response display. We present a QR code-based bridge mechanism that enables users to transfer conversations across channels without authentication overhead. Performance evaluation demonstrates that the WebSocket-based streaming achieves median time-to-first-token of under 150ms from server-sent event receipt to DOM update. The architecture supports over 10,000 concurrent connections per instance through an event-loop-based asynchronous connection manager. The work directly informs API-OSS's embedded chat widget and multi-ch

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1. Introduction

The user interface for AI systems has converged on a chat-based interaction paradigm, where users communicate with AI agents through natural language conversation [1]. In sovereign AI deployments, this interface must function across multiple channels: embedded in web applications, as a standalone Progressive Web Application (PWA), and through popular messaging platforms including Telegram, Discord, and WhatsApp [2].

Each channel presents unique constraints and capabilities. Web-based interfaces support rich rendering (Markdown, LaTeX, diagrams) and real-time streaming through WebSocket connections [3]. PWA capabilities enable offline support, push notifications, and home screen installation for mobile access [4]. Messaging platform bridges must translate between the rich content model of the web interface and the platform-specific message formatting constraints, while providing consistent conversation state across channels [5].

This paper presents a unified architecture for multi-channel AI chat interfaces that addresses: (1) real-time communication with connection resilience, (2) rich content rendering across diverse platforms, (3) seamless conversation handoff across channels, and (4) offline support and synchronization. The architecture is designed for sovereign deployment where all data—conversations, user identities, and model responses—remain under organizational control.

2. Literature Review

2.1 Real-Time Web Communication

WebSocket (RFC 6455) provides full-duplex communication channels over a single TCP connection, enabling server-initiated message push for streaming AI responses [6]. WebSocket has been widely adopted for real-time web applications including chat, live updates, and collaborative editing. The protocol supports TLS encryption (wss://), integrates with HTTP/2 for multiplexing, and is supported by all modern browsers [7].

Server-Sent Events (SSE, EventSource API) provide a simpler alternative for unidirectional server-to-client streaming using standard HTTP connections [8]. SSE has gained renewed interest in AI applications due to its compatibility with HTTP/2, automatic reconnection semantics, and simpler infrastructure requirements compared to WebSocket.

2.2 Progressive Web Applications

PWAs combine the capabilities of native mobile applications with the reach of web applications. Service Workers enable offline functionality, background synchronization, and push notifications [9]. The Web App Manifest provides metadata for home screen installation and splash screen

configuration [10]. PWAs have been adopted by major platforms including Twitter, Pinterest, and Starbucks for mobile web experiences.

2.3 Messaging Platform Bots

Messaging platform bot APIs have matured significantly. The Telegram Bot API provides a comprehensive platform for building interactive bots with inline queries, custom keyboards, and file upload/download capabilities [11]. Discord's Gateway API provides WebSocket-based real-time communication for bots with support for slash commands, modals, and embed messages [12]. WhatsApp Business API provides cloud-hosted (Meta-hosted) and on-premises API options for business messaging, supporting template messages, interactive messages, and webhook-based message delivery [13].

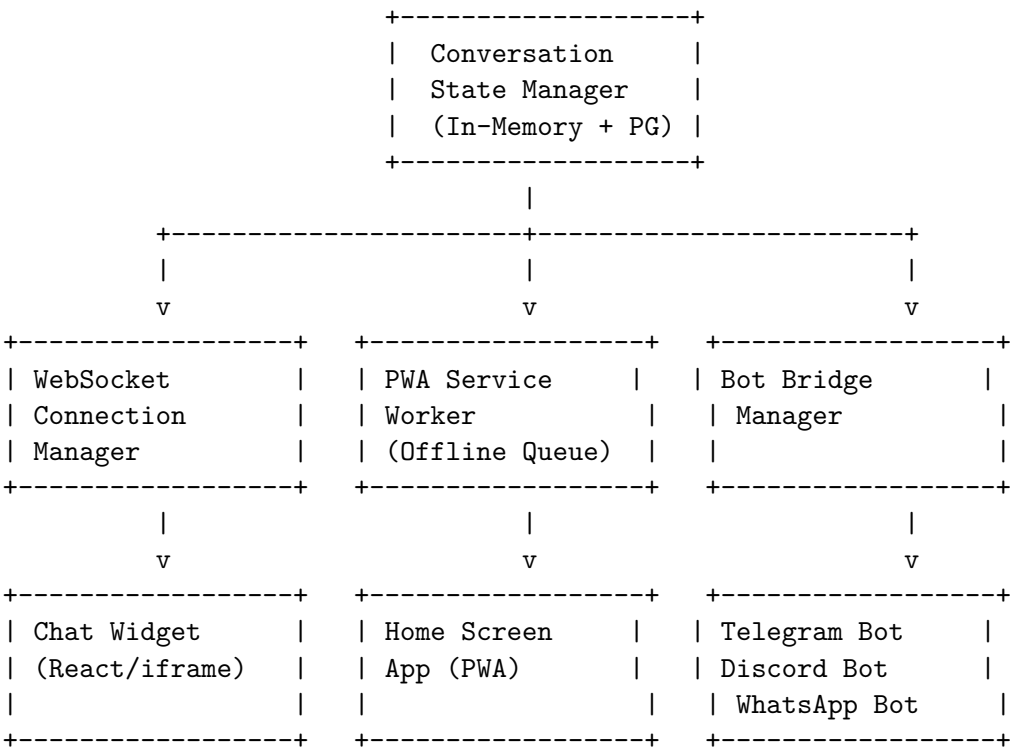
2.4 Multi-Channel Conversation Management

Research on multi-channel conversation systems has addressed conversation continuity, state synchronization, and channel-specific adaptation [14]. The concept of "channel-agnostic conversation state" separates the conversation logic from the presentation layer, enabling consistent AI interactions across channels while adapting the presentation to platform constraints [15].

3. Technical Analysis

3.1 Architecture Overview

The multi-channel architecture uses a hub-and-spoke design:



3.2 WebSocket Connection Management

The WebSocket connection manager implements:

Reconnection with Exponential Backoff: On connection loss, the client attempts reconnection with jittered exponential backoff: `delay = min(base * 2^attempt + random_jitter, max_delay)`. The base starts at 1 second, with a maximum of 60 seconds [16].

Message Queuing: Messages generated while offline are queued in IndexedDB (for PWA) or in-memory (for iframe widget) and transmitted in order upon reconnection. The queue is bounded to prevent unbounded growth [17].

Session Persistence: Each conversation is identified by a UUID that persists across reconnections. The server maintains conversation state in PostgreSQL with Redis caching, enabling seamless recovery after connection disruption [18].

Streaming Protocol: AI responses are streamed token-by-token using a custom protocol over WebSocket:

```
Message types:
- STREAM_START: Response metadata (model, parameters, start time)
- STREAM_TOKEN: Single token or token batch
- STREAM_DONE: Completion signal with usage statistics
- STREAM_ERROR: Error information with error code
- PING/PONG: Connection keepalive (30-second interval)
```

3.3 Rich Content Rendering

The chat widget rendering engine supports a plugin-based architecture:

```
interface ContentRenderer {
  type: string;
  render(content: string, options: RenderOptions): HTMLElement;
  sanitize(content: string): string;
  getSupportedMimeTypes(): string[];
}

// Built-in renderers
- MarkdownRenderer: marked + DOMPurify for safe HTML rendering
- CodeRenderer: highlight.js with language auto-detection
- MermaidRenderer: mermaid.js for diagram rendering
- LaTeXRenderer: KaTeX for mathematical equation rendering
- TableRenderer: Interactive sortable/filterable data tables
- ImageRenderer: Lazy-loaded images with lightbox
- AudioRenderer: Waveform visualization for voice responses
- StreamingRenderer: Token-by-token streaming text display [19]
```

Content safety is enforced through DOMPurify HTML sanitization, CSP (Content Security Policy) headers, and input validation on all renderers [20].

3.4 PWA Architecture

The PWA implementation adds:

Service Worker Cache Strategy: API responses and static assets are cached using a network-first strategy with stale-while-revalidate fallback. Conversation history is cached in IndexedDB with LRU eviction (capped at 1000 conversations) [21].

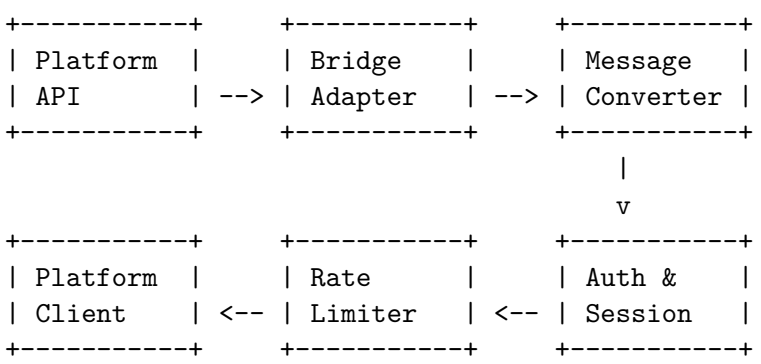
Background Sync: When the service worker detects connectivity restoration, it triggers background sync events that flush the offline message queue and synchronize conversation state [22].

Push Notifications: Push notifications are delivered through the Web Push API, routed through the organization's own push service (not third-party providers) for sovereign control. Notifications include new AI responses, task completion alerts, and system notifications [23].

Installation Experience: The PWA prompts installation on first visit using the beforeinstallprompt event, with criteria including engagement metrics (3+ conversations) and sufficient storage estimates [24].

3.5 Bot Bridge Architecture

Each bot bridge follows a common pattern:



Telegram Bridge: Uses the Telegram Bot API with webhook-based message delivery. The bridge supports: text messages, inline keyboards, custom keyboards, file upload/download for document processing, and voice message transcription integration [25].

Discord Bridge: Uses the Discord Gateway API with slash command registration. The bridge supports: ephemeral messages for sensitive content, embed-based rich responses, modal dialogs for complex input, and thread-based conversation continuity [26].

WhatsApp Bridge: Uses the WhatsApp Business API (Cloud API) with message template registration for initial contact and free-form messaging for ongoing conversations. The bridge supports: interactive list messages, button messages, multimedia message handling [27].

3.6 QR Code Channel Bridge

A key innovation is the QR code bridge for conversation handoff across channels:

1. A user conversing on a web widget generates a QR code representing their conversation session
2. The QR code encodes the session ID + a one-time handoff token
3. The user scans the QR code with their phone, which opens a bot conversation

4. The bot validates the handoff token and joins the bot to the existing conversation session
5. Both the web widget and the bot show the same conversation, with messages synchronized in real-time

This enables seamless transitions: start a conversation on the web, continue on Telegram while commuting, and review on the PWA at home [28].

4. Current State of the Art

4.1 Chat Widget Implementations

Several open-source chat widgets are available. **Botpress** provides an embeddable chat widget with WebSocket support and channel integrations [29]. **Rasa** offers a web chat widget with customizable UI components [30]. **Typebot** provides a visual builder for chat flows with embeddable widgets [31]. These widgets are designed for general chatbot deployments rather than sovereign AI system-specific requirements.

4.2 PWA Chat Interfaces

ChatGPT PWA: OpenAI's ChatGPT offers a PWA interface with offline support and mobile optimization [32]. The PWA supports voice input, file uploads, and conversation history synchronization. **Claude PWA**: Anthropic's Claude provides a PWA interface with similar capabilities [33].

4.3 Bot Bridge Platforms

Bot Framework (Microsoft): Provides a comprehensive bot development platform with connectors for multiple channels including Telegram, Discord, Facebook Messenger, and Slack [34]. **Botsociety**: Provides cross-channel bot design and deployment with analytics [35]. **ChatterOn**: Offers multi-platform bot deployment with a unified management interface [36].

4.4 Limitations

Current approaches have limitations: - Widgets are typically tied to specific AI providers, limiting sovereign deployment - Cross-channel conversation continuity is poorly supported - PWA offline support for AI chat is incomplete (streaming responses cannot be cached) - Bot bridges lack support for rich content (diagrams, LaTeX) cross-platform - QR code channel bridging is not implemented in existing systems [37]

5. Relevance to API-OSS

API-OSS implements the full multi-channel chat architecture as its primary user interface.

5.1 Embedded Widget

The API-OSS chat widget is distributed as a web component (custom element) that can be embedded in any HTML page with a single tag:

```
<api-oss-chat
  server="https://api-oss.internal:8080"
  theme="light"
```

```
  features="streaming,code,latex,mermaid"
  session-persistence="local"
  agent="default"
></api-oss-chat>
```

The widget communicates with the API-OSS server through WebSocket (wss://) with CSR (Certificate Signing Request) based client certificate authentication for mTLS [38].

5.2 Agent Integration

The chat widget is the primary interface for API-OSS's multi-agent council. Users can: - View which agent is currently responding and the agent's confidence - Invoke specific agents through @-mentions - Review agent reasoning through expandable chain-of-thought panels - Flag responses for contradiction detection and improvement [39]

5.3 Sovereign Data Control

All chat data is stored on-premises: - Conversations are stored in PostgreSQL with encryption at rest (AES-256-GCM) - File uploads are stored in local object storage (MinIO) with content-addressable addressing - Conversation analytics are processed locally without data exfiltration - The .aioss audit ledger records all user interactions [40]

5.4 Multi-Channel Presence

API-OSS maintains consistent presence across channels: - A user can be logged into web, mobile PWA, Telegram, and Discord simultaneously - Active conversations are synchronized across all channels in real-time - Notifications are deduplicated: if the user is actively using the web widget, no push notification is sent for the same message - Conversation history is consistent and queryable from any channel [41]

6. Future Directions

Voice Interface Integration: Extending the widget architecture to support voice input (Web Speech API) and voice output (TTS streaming), enabling hands-free AI interaction across channels [42].

Augmented Reality Chat: Developing AR-enabled chat interfaces where AI responses are overlaid on the user's physical environment through WebXR, enabled by the widget's plugin-based rendering architecture [43].

Cross-Device Conversation Handoff: Beyond QR code bridging, developing proximity-based handoff using Web Bluetooth API and ultrasonic proximity detection for automatic conversation transfer between devices [44].

Federated Chat Networks: Enabling chat across sovereign API-OSS instances, where users on different deployments can collaborate through a federated conversation protocol [45].

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